Role of Mechanics of Textile Preform Composites in the NASA Advanced Composites Technology Program

by

Charles E. Harris
Assistant Chief, Materials Division
and
C. C. Poe, Jr.

NASA Langley Research Center
Hampton, VA 23662

The Advanced Composites Technology Program

The Advanced Composites Technology Program was initiated by NASA as a partnership with the United States aeronautical industry in fiscal year 1989. The broad objective of the Program was to develop the technology to design and manufacture cost-effective and structurally optimized light-weight composite airframe primary structure. Phase A of the Program, 1989-1991, focused on the identification and evaluation of innovative manufacturing technologies and structural concepts. The prime contractors, Boeing, McDonnell-Douglas, and Lockheed, formed concurrent engineering teams to explore various innovative ideas and to begin the development and evaluation of the structural design concepts. At the end of Phase A, the leading wing and fuselage design concepts were down-selected for further development in Phase B of the Program, 1992-1995. (References 1-3 should be consulted for more details concerning the accomplishments in Phase A of the ACT Program.) Three major fabrication technologies emerged from Phase A as the most promising approaches to manufacturing cost-effective composite primary structures. These three approaches were the stitched dry preform, textile preform, and automated tow placement manufacturing methods. Each method emphasized rapid fiber placement, near net-shape preform fabrication, part count minimization, and matching the technologies to the specific structural configurations and requirements. The objective of Phase B was to continue the evolution of design concepts using the concurrent engineering process, down-select to the leading structural concept, and design, build, and test subscale components. Boeing and Lockheed were teamed together to focus on fuselage components, and McDonnell-Douglas was the prime contractor for wing components.

The issue of affordability of composite structure has emerged as a major technology challenge for the ACT Program. Because of the current poor

economic climate within the airline industry, most decisions regarding new airplane purchases are based on initial acquisition costs. Therefore, the widespread use of composite materials in primary structure will only occur if the cost of manufacturing a composite structure is lower than the cost of the corresponding metallic structure. Even though the cost per pound of the composite constituents may always be higher than aluminum, it is the cost of the finished structure that matters. Current state-of-the-art production costs of composite structure is almost twice the costs of corresponding aluminum airframe structure. However, the results from ACT Phase B are clearly indicating that composites can be cost competitive with metallic structure if cost efficiencies are achieved through innovative design and manufacturing technologies. (References 4-5 should be consulted for more details concerning the accomplishments in Phase B of the ACT Program.) The cost goal for ACT Phase C has been set at a 25% reduction in costs below that of corresponding aluminum structure.

Phase C of the ACT Program, 1995-2002, is a critical element of the NASA Advanced Subsonic Technology Program and has been approved for implementation beginning in 1995. The objective of Phase C is to design, build, and test major components of the airframe to demonstrate the technology readiness for applications in the next generation subsonic commercial transport aircraft. Part of the technology readiness demonstration will include a realistic comparison of manufacturing costs and an increased confidence in the ability to accurately estimate the costs of composite structure. The Program Plan calls for the structural components to be a complete fuselage barrel with a window-belt and a wing box at the wing/fuselage intersection. Proposals have been solicited from the major manufacturers to design, build, and test these composite structures. The procurement schedule calls for the prime contractors to be selected and the contracts awared by the end of fiscal year 1995. After the major contracts are awarded, the complete industry-University-NASA partnership will be completed with other program elements and team members being selected to support the activities of the prime contractors.

Subelement on Mechanics of Textile Preform Composites

Textile preform composites (braids and weaves) were the leading material form for the fuselage circumferential frames, window-belt reinforcements, and selected components in the keel of the fuselage. In addition, McDonnel-Douglas selected a knitted preform for the stitching technology for the wing components. To complete the development of the basic science underpinning to textile preform composites, the NASA Langley in-house team planned and implemented program elements focusing on fabrication technology, material system characterization, and mechanics-based design methodology. These

program elements were integrated with the programs of the prime contractors and became critical elements in the Phase B Program.

The Mechanics of Textile Preform Composites Program element had three primary objectives. First, test methods needed to be developed or modified to establish a set of test standards for measuring material properties and design allowables for textile preform composites. The standard test methods for tension, compression, and shear properties of laminated composites were evaluated and specialized for braided and woven preform composites. New test methods were developed to measure impact damage resistance and through-the-thickness strength. Second, mechanics models needed to be developed to predict the effects of the fiber preform architecture and constituent properties on engineering moduli, strength, damage resistance, and fatigue life. Micromechanics models were developed to predict the effects of the fiber architecture on local stress and strain behavior. The stress field results provided the basis for predicting the onset of various damage mechanisms and the strain field data were used to develop homogeneity methods for predicting the engineering elastic moduli of the composites. Third, an extensive experimental program was conducted to identify damage mechanisms and document damage progression and failure. A variety of loading histories were investigated including tension and compression strength of unnotched coupons, open-hole coupons and tubes with biaxial loadings, tension-tension and compression-compression fatigue, impact damage, post-impact residual strength, and post-impact fatigue. The experimental program led to the development of semi-empirical methods for predicting strength and fatigue life. More rigorous progressive damage models based on global-local analysis strategies were also developed for estimating strength and damage development due to impacts. However, these methods have limited capability and have not been experimentally verified.

The program objectives have been accomplished and the detailed results are presented by the Principal Investigators in this Proceedings. By the end of fiscal year 1995, the results will be integrated together into engineering design guidelines and a material property database will be assembled for all textile composites investigated in the Phase B Program. Taken together, the database and design guidelines will form the engineering basis for the detailed design of structural components using textile preform composites in Phase C of the ACT Program.

References

1. First NASA Advanced Composites Technology Conference, NASA CP 3104, compiled by John G. Davis and Herman L. Bohon, 1991.

2. Second NASA Advanced Composites Technology Conference, NASA CP 3154, compiled by John G. Davis and Herman L. Bohon, 1992.

3. Third NASA Advanced Composites Technology Conference, NASA CP 3178, compiled by John G. Davis and Herman L. Bohon, 1992.

4. Fourth NASA/DoD Advanced Composites Technology Conference, NASA CP 3229, compiled by John G. Davis, James E. Gardner, and Marvin B. Dow, 1993.

5. Fifth NASA/DoD Advanced Composites Technology Conference, NASA CP 3xxx, compiled by John G. Davis, James E. Gardner, and Marvin B. Dow, (1994).